# Analysis of Technology Improvement in Fuel Cell Vehicles

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## Overall Objectives

- Quantify the impact of system improvements on energy consumption and economic viability of light-duty fuel cell electric vehicles (FCEVs).
- Expand the analysis to medium- and heavy-duty vehicles by developing the assumptions, sizing algorithms, and test processes.

## Fiscal Year (FY) 2018 Objectives

- Quantify the impact of technology progress on light duty FCEVs.
- Estimate the technology progress assumptions applicable for fuel cell electric trucks (FCETs) and their impact on energy consumption and cost of the vehicle.

## Technical Barriers

This project addresses the following technical barriers from the System Analysis section of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration Plan[1]:

(A) Future Market Behavior

(C) Inconsistent Data, Assumptions, and Guidelines

(D) Insufficient Suite of Models and Tools.

## Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the FCTO Multi-Year Research, Development, and Demonstration Plan:

- Milestone 1.1: Complete an analysis of the hydrogen infrastructure and technical target progress for hydrogen fuel and vehicles.
- Milestone 1.17: Complete analysis of program technology performance and cost status, and potential to enable use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)

## FY 2018 Accomplishments

A comprehensive section on light-duty FCEVs was added to the Baseline Scenario (BaSce) analysis report published by Argonne. Analysis was extended to medium- and heavy-duty vehicles as well. Class 4 and Class 6 delivery trucks and Class 8 line-haul trucks were included in this analysis. Fuel cell- and storage-specific assumptions for trucks were developed for 2017–2050. Preliminary results on fuel consumption and cost are available now. This is being reviewed internally to support the work related to life cycle cost analysis.

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[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

## INTRODUCTION

Fuel cell technologies have achieved incremental improvements in cost reduction and durability since 2004 with DOE funding. Testing of commercial FCEVs reveals the peak efficiency of the fuel cell system to be close to 64%. Future technology improvements will reduce the cost of fuel cell stacks and improve their durability. In the analysis of light-duty vehicles, the primary task is to estimate when FCEVs will be economically more attractive to consumers. For this, various assumptions are made for future technology improvements. A detailed analysis of this is published in the BaSce report of 2018 [1].

Fuel cells also are getting more attention from the commercial vehicle segments (Class 4–8 trucks), as this provides a cleaner alternative to petroleum products. In comparison to other alternative technologies such as batteries, fuel cells provide a cleaner and cheaper way to drive longer distances without any downtime for charging. Several fuel cell truck prototypes developed with DOE funding are showing promising results. This study looks at how the technology would change in the future and estimates the impact on commercial viability of such trucks.

## APPROACH

### Light-Duty Vehicles

The National Highway Traffic Safety Administration (NHTSA) issued a notice of proposed rulemaking guidelines for the light-duty vehicles, and Argonne updated the vehicle models according to those guidelines. Various other assumptions related to vehicle attributes and vehicle component weights were also updated in consultation with NHTSA. In previous years, our analysis considered just five broad vehicle classes. Argonne expanded this list to 10 vehicle classes, with subcategories based on performance. This would adequately cover the breadth of light duty vehicles sold in the U.S. market. Table 1 details the different vehicle classifications along with the definition of the different performance categories used in the study.

Table 1. Vehicle classification and performance categories

| Vehicle Class | Performance Category | 0–60 mph time (s) |
|---|---|---|
| Compact | Base (Non Performance) | 10.0 |
| Compact | Premium (Performance) | 8.0 |
| Midsize | Base (Non Performance) | 6.0 |
| Midsize | Premium (Performance) | 9.0 |
| Small SUV | Base (Non Performance) | 9.0 |
| Small SUV | Premium (Performance) | 7.0 |
| Midsize SUV | Base (Non Performance) | 10.0 |
| Midsize SUV | Premium (Performance) | 7.0 |
| Pickup | Base (Non Performance) | 7.0 |
| Pickup | Premium (Performance) | 7.0 |

Light-weighting is applied across all glider systems except for those related to safety. Light-weighting is also applied to the wheels, except for tires. The details for each of the assumptions can be found in the report to NHTSA. For simplicity of the analysis of the report, only the assumptions for Midsize Base (Non Performance) vehicle are highlighted. The midsize base vehicle characteristics are as shown in Table 2.

Table 2. Vehicle characteristics for Midsize (Non Performance) FCEV

| Vehicle Attributes | Value |
|---|---|
| Vehicle mass (kg) | 1,653 |
| Drag coefficient | 0.300 |
| Rolling resistance | 0.0090 |
| Frontal area ($m^2$) | 2.35 |

### Fuel Cell Assumptions

Figure 1 illustrates the main assumptions for fuel cell vehicles from 2020 to 2045 lab years. The assumptions reflect the “high” technology progress case only.

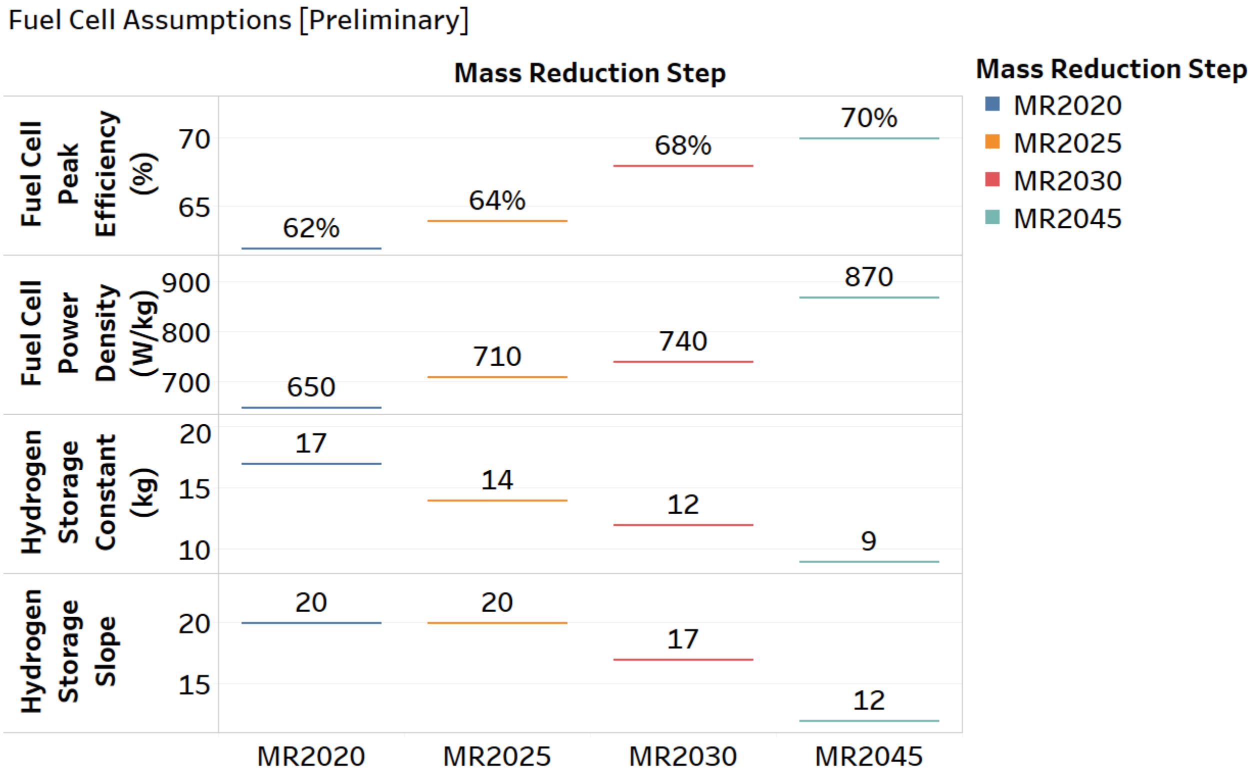

Figure 1. Fuel cell assumptions

## RESULTS

### Simulation Results

For simplicity of the analysis, only the midsize vehicle results (for both performance categories) are displayed in this section. Figure 2 shows the simulation results for midsize fuel cell vehicles from 2020 to 2045 lab years, followed by effectiveness of the same across lab years in Figure 3. For each lab year, the technologies that are expected to be available are implemented on the vehicle, and the power and energy requirements of various components are revised based on the sizing logic. For example, a lighter hydrogen tank will make the vehicle lighter, and this would help in reducing the fuel cell power and onboard hydrogen requirements.

To quantify the impact of the technologies we look at the reduction in fuel cell power requirement and improvement in overall fuel economy. Figure 3 shows the impact of the technology changes from 2020 to 2045. Fuel cell power requirement drops by about 20% for the midsize sedans if technology progresses as we assume. This would result in about 40% mass reduction of the fuel cell system. The lighter vehicle and more efficient component will improve the fuel economy of the vehicles. The fuel economy on city driving (UDDS) improves by about 37% and that on highway driving (HWFET) improves by about 29%. In a similar manner the effectiveness impact is quantified for all vehicles considered in this study.

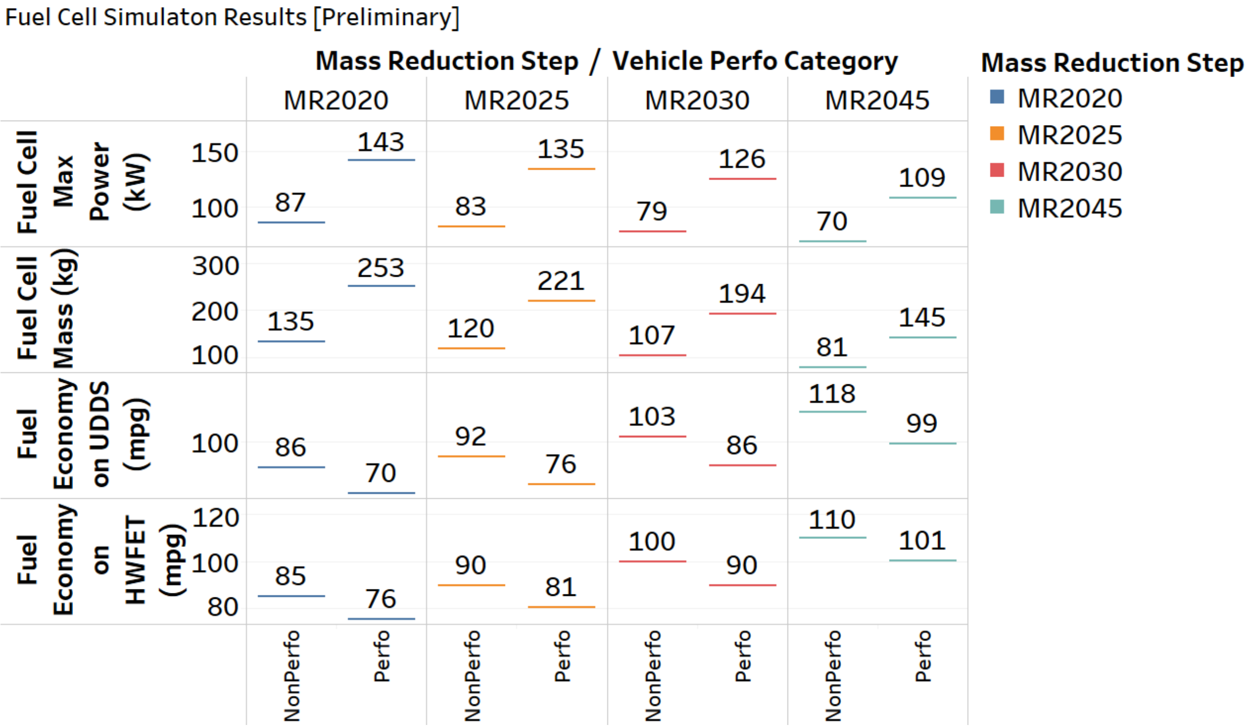

Figure 2. FCEV results across lab years for midsize vehicle class

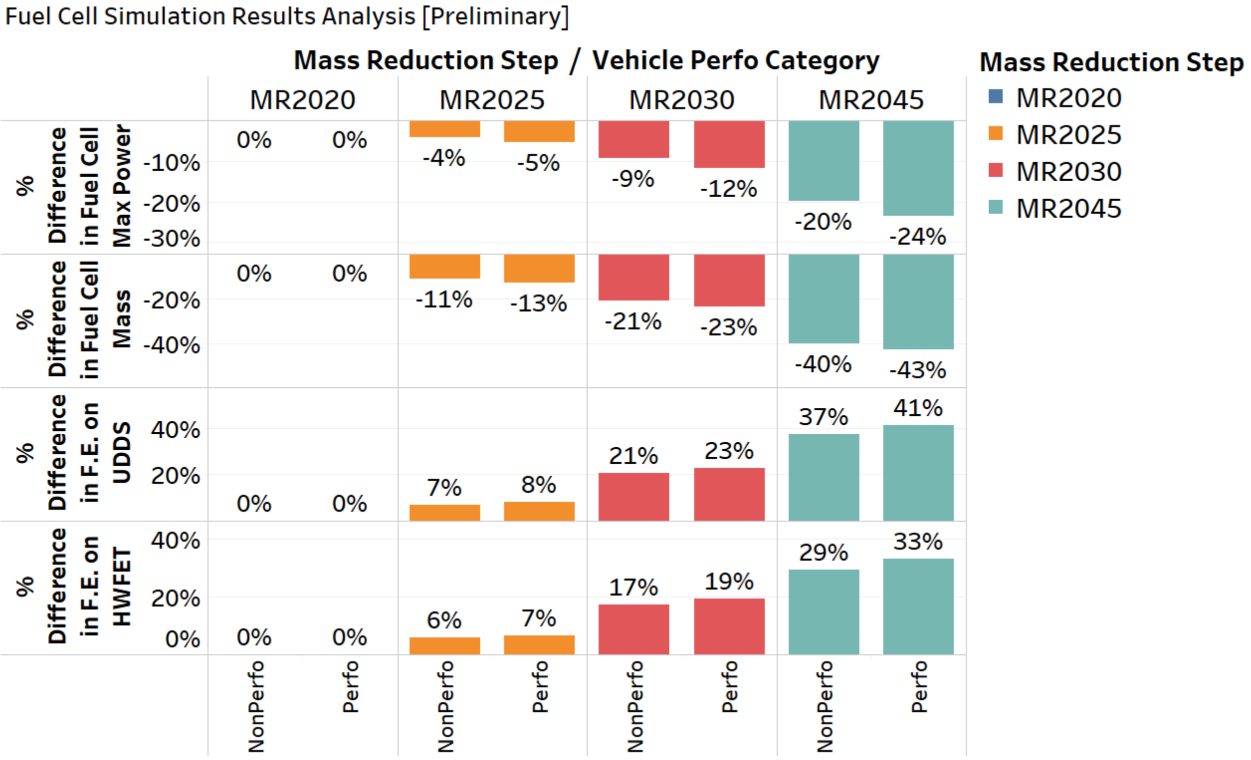

Figure 3. FCEV effectiveness across lab years for midsize vehicle class

### Medium- and Heavy-Duty Vehicles

The analysis of medium- and heavy-duty vehicles follows the same methodology as in the case of the light duty vehicles. It starts with technology improvement assumptions. While light-duty fuel cell assumptions have been widely reviewed and agreed upon by experts from DOE and industry, such assumptions are under development and review for FCETs. The workshop organized by FCTO at Argonne to identify the barriers and challenges to the use of fuel cells in trucks was a useful step toward developing these assumptions.

### Technology Progress Assumptions for Trucks

Prior work from Argonne had shown that the cost reduction of fuel cells and storage systems is more important than the improvements in efficiency or weight for light-duty applications. This may not be entirely applicable to the commercial vehicle segment, as cargo weight and volume is of critical importance in this application. In the case of both fuel cell and storage technologies, the impact of any present investment is not expected for the year 2020. The 'low' case estimates the technology progress without any DOE involvement, and the 'high' case sets the goals DOE is expected to achieve. All the years shown here are production years.

Figure 4 shows the assumptions made on fuel cell technology goals for the future. While light-duty systems have cost goals of ~$40/kW by 2025, the commercial vehicle fuel cells are likely to cost a lot more due to the much tougher operational and durability requirements. Figure 5 shows the hydrogen storage goals. The light-duty vehicle tank costs are estimated for storing 5–6 kg of hydrogen. Prior work on FCETs has shown that a 15 kg tank could meet the operational requirements of a wide variety of trucks, and two such tanks could store enough hydrogen to cover almost all applications except the Class 8 line-haul trucks, so the tank costs are estimated for 15 kg of hydrogen storage. The assumptions and equations related to the storage pressure, material design, and cost are kept the same as in the light duty BaSce analysis.

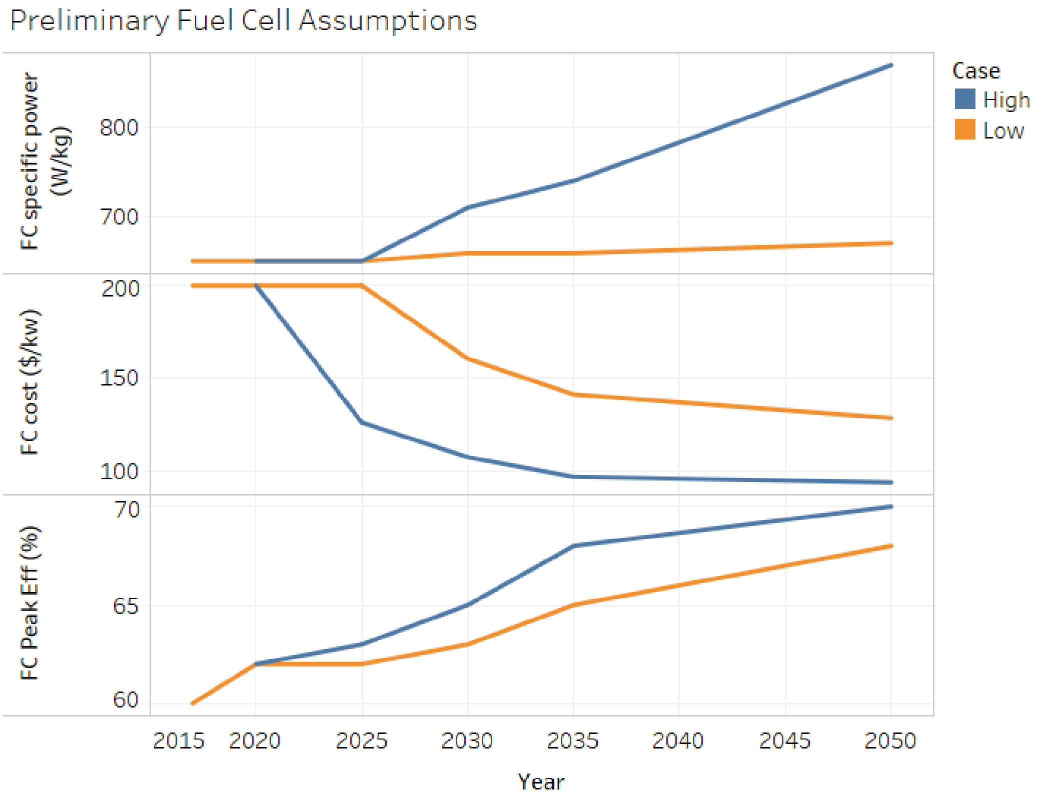

Figure 4. Fuel cell assumptions for trucks

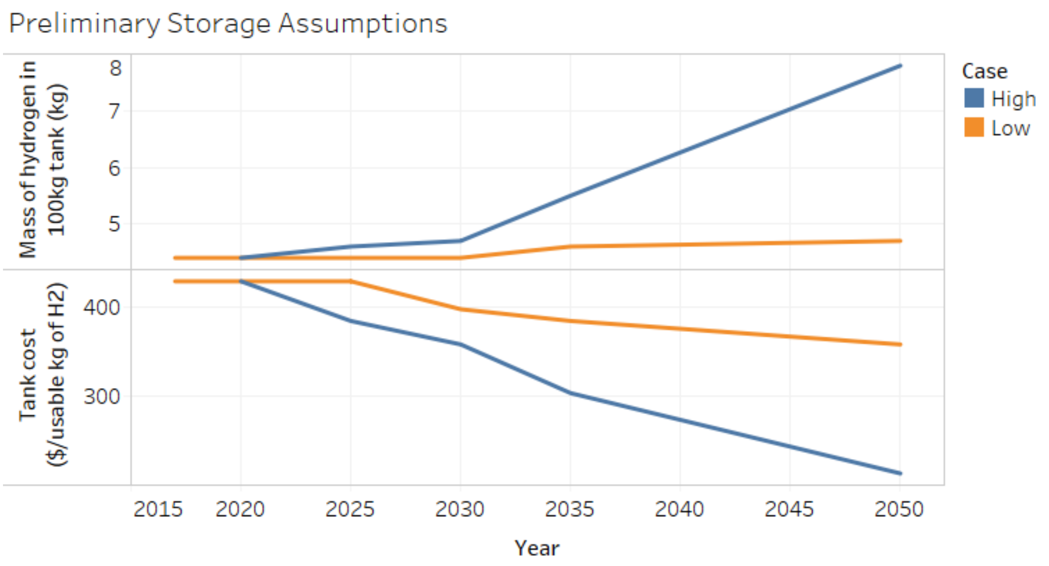

Figure 5. Storage technology assumptions for trucks

### Vehicle Assumptions

For analysis, two vehicles are identified from the vast array of commercial vehicles. Class 4 delivery vehicles and Class 8 line-haul trucks are chosen to evaluate the impact of technology. They are two extreme cases in terms of the operational requirements. A Class 4 delivery truck normally runs under 100 miles a day and returns to its operational base at least once a day. The yearly driving distance is typically within 15,000 miles. As vehicle miles traveled is low, fleets tend to own such trucks for a long time, and 10- to 15-year-old trucks are not uncommon in this use case (e.g., last-mile delivery trucks of USPS, UPS, FedEx). The line-haul trucks have entirely different operational requirements. They should be able to drive at least 500 miles without stops to be commercially competitive. They should also be able to drive more than 100,000 miles a year and should have a useful life over 1 million miles. In both cases, the weight and volume of the fuel cell system is critical. It should not reduce the cargo carrying capacity of these vehicles.

Vehicle performance requirements for these vehicles are shown in Table 3.

Table 3. Performance Requirements from Medium- and Heavy-Duty vehicles

| Class | Purpose | 0–30 mph (s) | 0–60 mph (s) | 6% grade speed (mph) | Max. Speed (mph) | Daily Driving Range (miles) |
|---|---|---|---|---|---|---|
| 4 | Delivery | 10 | 28.5 | 40 | 70 | 150 |
| 8 | Tractor | 18 | 66 | 30 | 65 | 500 |

As part of the BaSce analysis, conventional, hybrid, plug-in, and electric vehicles are also evaluated along with FCETs. All these vehicles have to achieve or exceed the above-mentioned performance requirements.

### Sizing Process

Sizing process is adapted from the methodology developed for another FCTO-funded study [2]. The vehicle models are developed using Autonomie [3]. The recent workshop conducted by FCTO at Argonne on identifying the barriers for FCETs also informed this process. While the earlier method accounted for sizing one vehicle using off-the shelf components, this new analysis extends it to using projected technology improvements.

A full report on sizing and fuel consumption estimates will only be ready after the simulations for energy consumption are carried out. A preliminary draft is being prepared and expected to be issued by Q2 of FY19.

## CONCLUSIONS AND UPCOMING ACTIVITIES

On light-duty vehicles, this study shows the relation between improvement in technology and the benefits realized at the vehicle level. By 2050, the fuel cell size requirements will come down by ~20% for midsize cars. The improvement in efficiency and reduction in mass could result in 30%–40% improvement in fuel economy.

On medium- and heavy-duty vehicles, the assumptions for technology improvements and cost are under review. The sizing process is published and reviewed. The detailed analysis of energy consumption and ownership costs will be available after the simulations are completed. This is expected by mid FY19.

## FY 2018 PUBLICATIONS/PRESENTATIONS

1. E. Islam, N. Kim, A. Moawad, and A. Rousseau. *An Extensive Study on Sizing, Energy Consumption, and Cost of Advanced Vehicle Technologies*. Report to the U.S. Department of Energy. ANL/ESD-17/17 (August 2018).

## REFERENCES

1. E. Islam, N. Kim, A. Moawad, and A. Rousseau. *An Extensive Study on Sizing, Energy Consumption, and Cost of Advanced Vehicle Technologies*. Report to the U.S. Department of Energy. ANL/ESD-17/17 (August 2018).
2. J. Marcinkoski et al. “Medium and Heavy Duty Fuel Cell Electric Truck Component Sizing.” Presented at EVS 2017, Canada.
3. Autonomie, available from www.autonomie.net.